Phase One Results Summary

The following is a brief summary of results achieved in Phase One of the Galvin Electricity Initiative. These results are described in more detail in the final task reports, which are available on the Galvin Electricity Initiative Web site (http://www.galvinelectricity.org).

The emphasis during Phase One was on the convergence of 21st century U.S. consumer service needs and expectations (industrial, commercial and residential), with the spectrum of technological capabilities — both existing and on the horizon — as related to electricity. The focus was not on electricity for its own sake, but on the functionality and services that electricity can ultimately provide to consumers through end-use processes, devices and appliances. The results describe the structure of innovation guiding the achievement of the Initiative's ultimate goal. That is, the comprehensive blueprint and roadmap (including technology, policies, incentives, business models, etc.) for achieving an absolutely reliable and robust U.S. electricity supply and service capability — one that perfectly meets the needs and expectations of all 21st century consumers under all conditions. In short, a system that cannot fail.

Collectively, the Phase One tasks examined, interactively and in-depth, the consumer and technology factors that are expected to have the greatest impact on 21st century electric energy utilization and the corresponding system performance requirements. The electricity system considered here includes all elements in the value chain that ultimately enable electricity to be transformed into useful services. This value chain extends beyond the consumer interface (e.g., the meter) to include the various end-use energy-consuming devices and appliances. During the course of Phase One, a group of more than 60 diverse independent experts encompassing every aspect of innovative power system design and advanced technology were assembled in four separate workshops to both advise on and evaluate the Initiative's progress.

<u>Task 1 — Consumer Needs</u>

This task examined, through a series of plausible alternative scenarios, how the broad consumer values of confidence, convenience and choice may evolve over the next 20 years. The first step in developing these scenarios was to identify the principal factors that will determine how the United States evolves economically and socially over this period. More than 100 potential drivers were considered and organized into six areas:

1. demographics
2. economics
3. environment
4. security & health
5. society & culture
6. technology

These drivers and their associated uncertainties were then organized into four distinct scenarios, each representing a quadrant in a two-dimensional matrix defined by two dominant societal trend axes: social fragmentation vs. social unity; and preference for mass-market solutions vs. customized solutions. Figure B-1 indicates these axes and the resulting scenario quadrants. Figure B-2 compares and contrasts these four scenarios in terms of answers to three fundamental questions: What is important to consumers/citizens? Who has the primary power to affect change? And, how are changes made?

Figure B-1: Quadrants

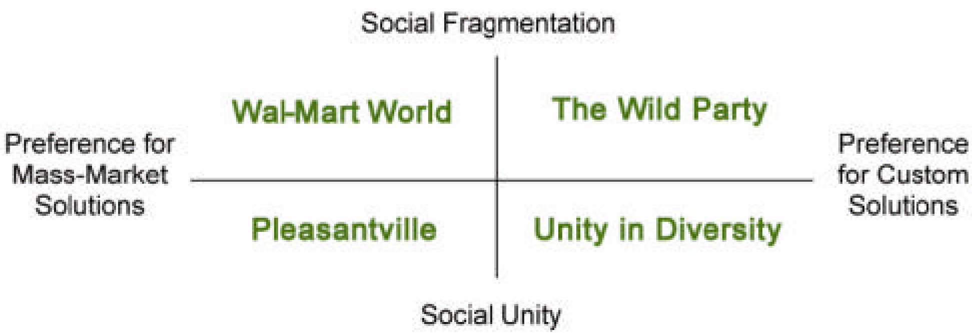

Figure B-2: Answers to critical questions by scenario

	Wal-Mart World	The Wild Party	Unity in Diversity	Pleasantville
What is important to consumers/ citizens?	Sub-cultural identities/ affiliations, personal safety, economic prosperity	Diversity, personal safety, change and experimentation	Creativity, collaboration and strength through diversity	Economic prosperity, social conformity and traditional middle -class values
Who has the primary power to affect change?	Corporations and sub-cultural groups	Individuals (particularly the wealthy) and corporations	Creative individuals, entrepreneurs and government	Government, corporations and other institutions
How are changes made?	Market mechanisms	Locally and individually	Peer-to-peer adoption and adaptation of new ideas	Centralized planning; national institutions

These four contrasting scenarios encompass a diverse variety of specific electric service needs and opportunities, but they also point to a number of robust consumer electric service-related expectations irrespective of the scenario. These include:

- Greater end-use energy efficiency
- Increased power reliability and quality
- Higher quality artificial illumination
- High-performance manufacturing with greater automation and energy efficiency
- More energy-efficient personal transportation
- Greater power portability
- Improved indoor air quality
- Improved water quality and availability
- Remote, real time medical diagnostics, and anticipatory care capabilities
- Enhanced personal security
- Connective Electricity/communications connectivity
- Universal telecommuting capabilities
- Differentiated, individualized electricity services
- Greater control of energy service terms and conditions

These service expectations derive from two underlying trends that dominate the foreseeable electricity energy service environment:

1. The comprehensive transformation of the U.S. economy and society from an analog mechanical to a digital electronic enabling structure. This correspondingly transforms the requirements for electric energy service reliability and quality.

2. The rising cost of all forms of energy, leading to increasing emphasis on the value potential of electricity. This value potential is driven by the unique ability of electricity to most efficiently bring the wide array of domestic energy resources to market while also enabling much greater end-use efficiency through "smart" services and devices.

Task 2 — Potential for End-Use Energy Technologies to Improve Functionality and Meet Consumer Expectations

Task 2 focused on the potential for technical functionality advancement in the field of electricity use. This involved an assessment of the global energy technology horizon in terms of early indications of innovative electricity end-uses, distributed resources, power electronics, and power quality technologies that have the potential to more perfectly meet consumer expectations.

As a first step, trends were evaluated that could potentially influence technology innovation in the residential, commercial, industrial and transportation end-use sectors respectively. These trends included: energy use, efficiency gains, consumer behavior, environmental regulations and maintenance requirements. Next, an expert workshop was conducted to identify the most significant potential end-use technology innovations (within a timeframe of 10–20 years), and to delineate the requirements for successful application of these innovations. The 12 technology application areas that were judged to have the greatest potential to influence future consumer needs and contribute to achieving the Perfect Power System were selected for further evaluation. These areas were:

- Lighting
- Space conditioning
- Indoor air quality
- Domestic water heating
- Water and wastewater treatment
- Waste management with biofuel production
- Manufacturing processes
- Information technology
- Distributed generation
- Electric energy storage
- Portable power
- Power quality

Each of these technology application areas was then evaluated for its potential contribution to achieving the Perfect Power System in terms of the following categories: reliability, health and safety, resiliency, energy efficiency, demand-responsiveness, power quality impact, environmental impact, and functionality.

Within each of these technology application areas, a number of specific technologies were also identified as having the greatest contribution potential in terms of improving functionality and meeting consumer expectations within the context of achieving the Perfect Power System. These technologies are listed below:

High Potential Enabling Technologies

1. Active magnetic regenerative cooling
2. Advanced oxidation processes
3. Carbon dioxide cycle for space conditioning/refrigeration
4. Concentrated solar energy
5. Daylight harvesting
6. Demand-controlled hybrid ventilation
7. Desiccant dehumidification technologies
8. Fiber optics in light-sensitive material
9. Flywheels
10. High pressure electrolyzers
11. Hybrid electric vehicles
12. Integrated smart lighting
13. Light engines
14. Lithium batteries
15. Nanotechnologies
16. Photoluminescence materials
17. Photovoltaics
18. Pipe lighting/solar light tubing
19. Polymer electrolyte membrane fuel cells
20. Power electronics
21. Simplified network management protocols
22. Stirling engines
23. Ultracapacitors
24. Ultraviolet germicidal irradiation
25. Variable speed motor drives
26. White light emitting diodes

Each of these specific technologies will be evaluated in more depth during Phase Two of the Initiative to more thoroughly determine both the performance improvement potential and the costs/benefits associated with resolving the current performance gaps in each relevant technology application area.

Figure B-3 summarizes the logic relationship between consumer needs, technology trends, and specifications for the Perfect Power System.

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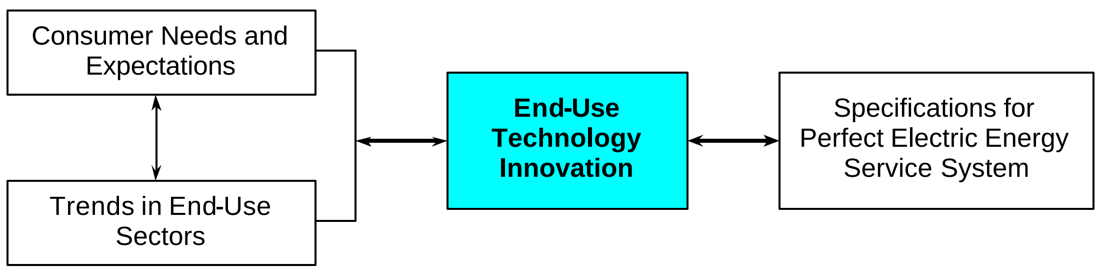


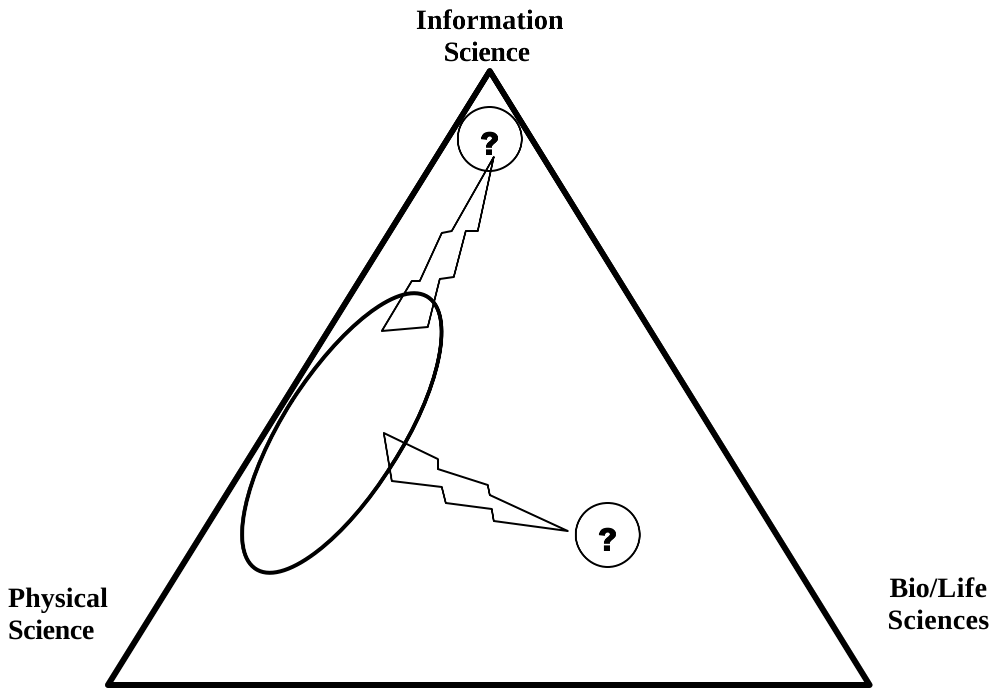
Task 3 — Technology Scanning, Mapping and Foresight

Task 3 investigated the potential for applications of science and technology outside the traditional energy sector to facilitate achievement of the Perfect Power System, particularly in terms of most perfectly meeting the evolving needs and expectations of consumers identified in Task 1. Particular technology performance gaps that were explored by this task included: ubiquitous, hierarchical computational capabilities and sensors to enable real-time predictive power system control and state estimation; low-cost enhanced energy storage; self-contained cellular AC and DC microgrids; advanced, post-silicon power electronics; zero net energy buildings; enhanced power portability; high-efficiency, smart end-use devices and appliances; clean, cost-effective small-scale distributed power generation; and more effective consumer-focused power market design and operating tools.

Filling these gaps and meeting the service expectations and energy requirements of both individual consumers and society will require the application of a combination of advanced technologies. These technologies must enable a power system that: is scalable; is robust under all conditions; allows technology breakthroughs to be exploited rapidly and effectively; enables a differentiated price/performance-based market for electricity; and is aligned economically and politically so as to provide simultaneous incentives to all stakeholders. The likely result will be localized, building-integrated and/or microgrid-based power systems that grow and self-organize in response to individual user needs, and that complement the existing macro power grid structure. Such decentralized system architectures also avoid the negative consequences of nonlinear dynamics that tend to dominate highly integrated bulk power systems.

Specific advanced technology areas that were determined to have the greatest contribution potential for filling the performance gaps in perfecting such a power system include: a) nanotechnologies for energy storage; b) smart materials including piezoelectric polymers, shape-memory alloys, conductive polymers, hydro gels and fiber optics; c) biomimetic materials and designs; d) fullerenes for nanoscale electronic devices; e) information technology to enable real time, automated monitoring and control of dynamic power systems; and f) advanced sensors that overcome limitations on temperature, versatility, size and chemical environment. Applying these advanced technology areas will, in effect, move the electricity sector's Technology Power Zone (Figure B-4) from its traditional focus on the physical sciences to a more strategically effective balance in terms of utilizing the information sciences and the bio/life sciences as essential technological assets.

Figure B-4: Extending or moving the Technology Power Zone: The key strategic technological innovation questions for the electricity enterprise



Several scenarios were developed to demonstrate the technological opportunities to advance electric energy system reliability and performance within the next 10–20 years. These scenarios include: Grid Independent Communities; Consumer-Focused Local Area Networks and Microgrids; and Semi-Autonomous Power Systems. Related technological opportunities include intelligent power system management, distributed micropower, plug-and-play appliances/devices, modular fractal grid configurations, and distributed control. Common to these emergent system scenarios is their self-organizing structure based on meeting individual consumer needs and expectations. These scenarios also clearly demonstrate the importance of moving to a more strategically effective asset balance among the physical, information and bio/life sciences.

Task 4 — Analysis Framework

Task 4 had two basic objectives. First was to develop an analytical framework and capability for consistently evaluating the various Technology Innovation Nodes and potential Perfect Power System Configurations identified in Phase One. The second objective was to provide a clear "line of sight" to Perfect Power System value creation, including stakeholder value metrics beyond the reach of traditional cost-based accounting systems. In Phase Two, this framework will be used to: a) perform comprehensive evaluations of key enabling technologies and alternative system Configurations, and (b) to incorporate the various performance- and implementation-related economic, social, environmental, political and quality of life stakeholder value metrics that will influence the commercial potential of these system Configurations.

Six requirements were defined in terms of determining a confident course of action leading to Perfect Power System creation:

1. Appropriate decision framework and perspective
2. Creative, achievable alternatives
3. Balanced stakeholder values, tradeoffs, and risk tolerance
4. Meaningful, reliable and comprehensive information
5. Logical, well-structured, method for evaluating alternatives
6. Achieve stakeholder commitment to action

The analytical framework for evaluating Innovations and Configurations can be considered to be perfect when it is 100 percent aligned with the Initiative's vision and accommodates these decision requirements. When the appropriate framework is close to 100 percent of the vision, then the alternatives, values and logic all fit the framework.

The following stakeholder value metrics were identified for consideration in Phase Two:

- Net energy cost
- Adequacy (capacity)
- Security
- Availability
- Major outage risks
- Environmental impact
- Fuel vulnerability
- Quality of life
- Portability
- Productivity
- Safety
- Choice
- Functionality
- Appearance
- Customer service
- Self-organizing capability

Applying the analytical framework and value metrics will involve a series of 10 iterative steps:

1. Describe each potential Perfect Power System Configuration.

2. Confirm the Innovation Nodes and their corresponding key enabling technologies.

3. Review the supporting technologies that may influence the key enabling technologies.

4. Assess the uncertainty ranges for the key variables affecting each candidate Innovation Node and its enabling technologies.

5. Identify the critical technology capability gaps in achieving perfect performance.

6. Develop computational worksheet models for evaluating the alternative system Configurations and Innovation Nodes. These will be based on diagram-based value templates developed for each system Configuration, Innovation Node and enabling technology.

7. Perform sensitivity analyses on each Configuration and Innovation Node to identify the relative value and risk contributions of key performance factors, enabling technologies and associated uncertainties.

8. Develop risk-return profiles for the various Innovation and Configuration alternatives.

9. Compare and prioritize the Innovation and Configuration alternatives using the risk-return profiles.

10. Develop an integrated funding curve for each final alternative system Configuration to ensure that resources are allocated to the highest value system alternatives and enabling Innovations.

In Phase Two, this evaluation process will be used to define the highest value development and implementation strategy for each potential Perfect Power System Configuration. This will be the basis for completing the specific system blueprints and roadmap supporting commercial implementation.

Task 5 — Developing Functional Requirements for the Perfect Power System

The objective of Task 5 was to translate the results of the various preceding Phase One tasks into functional specifications for the electric energy system, including the end-use devices and the power supply capabilities that support them. In meeting this objective, Task 5 synthesized the work from the previous tasks and focused on the definition of potential Perfect Power System Configurations by leveraging the various Innovation Nodes that were identified. In order to provide service perfection to all energy uses, the Perfect Power System(s) must meet the following overarching goals:

- Be smart, self-sensing, secure and self-correcting
- Sustain failure of individual components without interrupting service
- Be able to satisfy specific, individual consumer needs
- Be able to meet all consumer needs at reasonable value-based cost with the most efficient resource utilization and minimal environmental impact
- Enhance quality of life and improve economic productivity

The design criteria to meet these goals, and the associated performance specifications, must in turn address the following key power system components and parameters:

- End-use energy service devices
- System configuration and asset management
- System monitoring and control
- Resource adequacy
- System operations
- Portability
- Connectivity with communications

No potential Perfect Power System Configuration is capable of being deployed today in a manner that perfectly achieves the overarching performance goals listed previously without technological advancement in the various Innovation Nodes. The following are key enabling technologies as identified by the Research Team and the various Phase One expert workshops:

Innovation Node	Key Enabling Technologies
1. Communications	Consumer portal
2. Computational ability	Fast simulation modeling
3. Distributed generation	Microturbines, combined residential heat and power
4. Power electronics and controls	Inductive charging, low/medium voltage power controllers
5. Energy storage	High energy density batteries, super conductors, direct methanol fuel cells
6. Building systems	Heat pump water heating/space conditioning, building-integrated photovoltaics.
7. Appliances and devices	White light emitting diodes
8. Sensors	Low power wireless smart sensors

An essential focus of Phase Two will be on resolving any barriers, hurdles and uncertainties that influence the ability of these key technologies, and their associated Innovation Nodes, to perfect the candidate Perfect Power System Configurations.

The basic philosophy for developing the Perfect Power System is to: a) increase independence, flexibility and intelligence for optimization of energy use and management at the least complex system configuration level; and b) integrate these system Configurations at higher levels to the extent necessary for delivering perfect power, including both reliability and energy service value optimization. The following levels of system integration on the path to perfection were identified by the Task 5 Research Team:

1. Portable (device) power
2. Building-integrated (localized) power
3. Distributed power
4. Fully integrated power

Figure B-5 is a pictorial representation of the various enabling technologies and their associated Innovation Nodes outlined above, in the context of this series of four potential Perfect Power System Configurations.

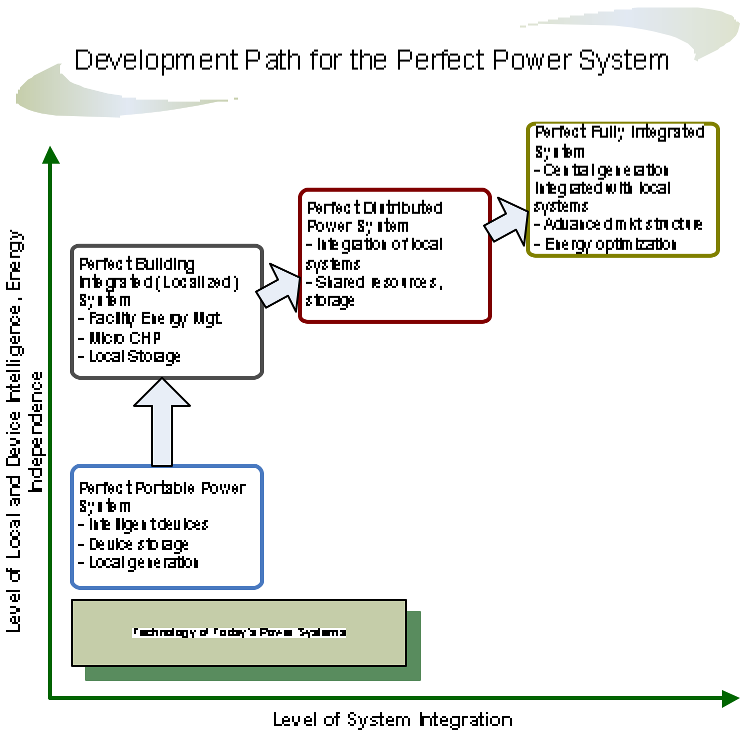
Figure B-5: Relevant technologies that enable Innovation Nodes

Portable device power represents the most independent and least complex system configuration. Not only does portability enable a highly mobile digital society, but it also provides elements of perfection which, in turn, enable building integrated local power systems. These microgrid-based systems accommodate increasing consumer expectations for independence, convenience, appearance, environmentally friendly service and cost controllability. Once localized microgrid-based perfect systems are achieved, they can be linked together to create distributed perfect systems that can interconnect with the existing local power distribution networks. These, in turn, can be interconnected through technologies that enable the fully integrated regional, and ultimately national, Perfect Power System.

Contrary to conventional electricity sector wisdom, this approach to achieving perfection starts with the consumer. In addition, each Configuration reflects both a much more decentralized level of monitoring and control, and a complementary set of milestones on the path to comprehensive national power system perfection. Each Configuration also opens new avenues for entrepreneurially led development and implementation.

These Configurations reflect system development in two important dimensions: 1) level of intelligence and capability in distributed devices and systems; and 2) level of integration of the entire power delivery infrastructure. The development path for the four potential Perfect Power System Configurations is depicted in Figure B-6.

Figure B-6: Development path for the Perfect Power System



The following summarizes some of the distinguishing characteristics of each of these potential Perfect Power System Configurations and their relevant Innovation Nodes.

- **Portable Power Device Systems.** The reliability and quality of equipment and processes is determined locally to minimize failure modes. It is the most flexible Configuration and is least dependent on any existing infrastructure. Finally, innovations in end-use technologies can be utilized immediately without significant issues of control and integration with the existing static power delivery system.

- **Building Integrated Power Systems.** Energy supply can be optimized here across a more diverse variety (both type and size) of distributed energy sources, resulting in improved power generation reliability and economics. It also creates a microgrid infrastructure for more optimal management of overall energy requirements than is possible with a portable system, while still allowing local control and reliability management.

- **Distributed Power Systems.** The distributed power system involves the interconnection of independent Building-Integrated Systems and microgrids to allow sharing of generation and storage capabilities over wider areas. This can also include interconnection with the local power distribution system. Communication and control is still localized, as well as energy management, but a broader array of centralized generation sources can also be considered, although at some increase in infrastructure complexity. In this Configuration, energy performance can be optimized through a market structure where appropriate values are placed on all important resource and performance parameters.

- **Fully Integrated Power Systems.** The final level of power system perfection involves a Configuration that enables the complete integration of the power system across wide geographic areas. The primary difference between this Configuration and the distributed power system is the inclusion of multiple centralized generation sources linked through high voltage networks. The design enables full flexibility to transport power over long distances in order to optimally utilize generation resources and most efficiently deliver power to load centers that are coupled through the transmission backbone. Creation of the complex, real time, information infrastructure to support these optimization functions is the primary additional development needed to achieve the Fully Integrated Power System.

The last step in Task 5 was to identify the issues and barriers that might restrict attainment of the Perfect Power System. It was concluded that all of these considerations can be resolved and none pose an insurmountable barrier to achieving the Perfect Power System as envisioned by the Galvin Electricity Initiative. The essential factor here is maintaining absolute priority on the quality criteria that are essential to perfection.

Issues and Barriers to be Resolved

- Political risk aversion
- Regulatory inertia
- Incumbent resistance to change
- Absence of key enabling technologies
- Demand/price inelasticity
- Non-uniform regulations
- Distributed generation costs
- Smart service control capabilities at the consumer level
- Absence of incentives for efficient end-use devices and appliances
- Misalignment between who pays and who gains
- Lack of a uniform vision of the Perfect Power System
- Lack of truly competitive retail electricity markets
- Dominant supply-driven incentives

Phase Two will further consider these issues and barriers in the context of achieving the Perfect Power System. This will include four steps: 1) translating the generic potential Perfect Power Configurations into a set of specific system designs for commercial application; 2) expanding the Phase One analysis framework to incorporate performance- and implementation-related economic, social, environmental, political and quality-of-life factors that can influence the potential value and risk of these system designs; 3) performing comprehensive evaluations of the key technologies and Innovation Nodes they support to identify the greatest perfection potential over the next 10–20 years; and 4) developing implementation blueprints, roadmaps and business plans describing the major activities that will be required to implement these specific power system designs and their supporting innovations with absolute perfection.